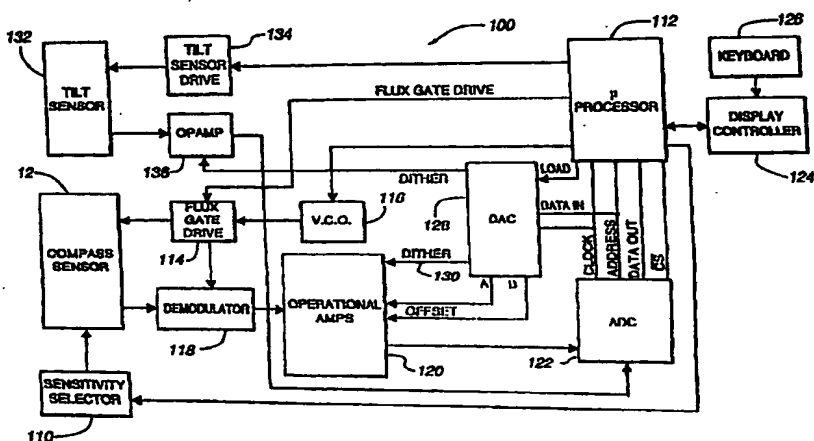




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(54) Title: TILT COMPENSATION APPARATUS AND METHOD FOR USE WITH A MONOPOD MOUNTED LASER RANGE FINDER APPARATUS



## (57) Abstract

A tilt compensation method, circuit and apparatus (Figs. 5 and 8) utilizes a two axis tilt sensor or two single axis tilt sensors (40; 132) for alerting a user and/or compensating a surveying instrument (10) for off vertical alignment above a reference point when the instrument support is free to move about the reference point e.g., when mounted on a monopod support (14). The sensor comprises a cell having a central electrode and four peripheral electrodes (54a, 54b, 54c, 54d) spaced 90 degrees apart around the central electrode. A microprocessor (42; 112) preferably provides a square wave drive signal selectively to alternate pairs of the opposing electrodes through tristate buffers (72) while at the same time the microprocessor (42; 112) provides a channel select signal (64) to the gate of the tristate buffers to float the idle electrodes. The signal on the central electrode is fed to an ADC (70) and then to the microprocessor (42). The microprocessor preferably produces an alarm signal (50) if the tilt is more than a user determined value.

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**TILT COMPENSATION APPARATUS AND METHOD FOR USE WITH  
A MONOPOD MOUNTED LASER RANGE FINDER APPARATUS**

**BACKGROUND OF THE INVENTION**

**5   Field of the Invention:**

The present invention relates, in general, to the field of surveying instruments. More particularly, the present invention relates to an apparatus and method for compensating a laser based surveying instrument for non-vertical mounting structure alignment.

**10   Description of the Related Art:**

Conventional surveying instruments such as Laser Technology, Incorporated's laser based Criterion series surveying instruments are designed for mounting on a stable tripod which is leveled and held stationary directly over the location from which measurements are to be  
**15   based.** Setting up a surveying instrument in this manner, precisely leveled, especially in rugged terrain is a very time consuming process.

First, a suitable site must be found upon which a tripod can be leveled over the precise point on the ground from which measurements are to be taken. Second, the tripod must be set up with the instrument mounting plate at the apex of the tripod level. Third, the level tripod  
**20   must be oriented with the aid of a plumb bob such that the center of the mounting plate is exactly over the ground point being measured from.** Fourth, the instrument mounted on the mounting plate is then aimed at the target. Next, the level and plumb of the instrument base is again  
**25   checked.** Finally, the measurement is taken and the level and plumb of the instrument base is rechecked again. After each rotational or inclinational movement of the instrument the level and plumb of the instrument is also rechecked to ensure that the support structure has not changed. If it has, the instrument base must be re-leveled and re-  
**30   plumbed.**

All of these manipulations require substantial time to perform. What is needed, then, is a mechanism which enables simply setting up the measuring instrument so as to eliminate some or all of the time consuming setup steps just described without sacrificing accuracy of the resulting measurements. Further, an automatic compensation circuit to compensate the measurement automatically for inaccuracies in physical instrument mounting configurations would be highly desirable.

10

### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method of warning an operator of a surveying instrument mounted on a monopod support when the support is deviating from an acceptable off vertical alignment so that the operator can maintain the instrument within acceptable limits.

15

It is another object of the present invention to provide a warning circuit device for surveying instruments mounted on a support such as a monopod to provide a warning to the operator when the support is out of vertical alignment by a predetermined amount so as to eliminate the need for a leveled support.

20

It is another object of the invention to provide a warning device for surveying instruments mounted on a support fixed in only one dimension to provide a relative quantitative indication to the operator when the instrument support is out of vertical alignment by a predetermined amount and conversely when the instrument is within acceptable limits of vertical alignment.

25

It is another object of the present invention to provide an automatic compensation circuit for incorporation into conventional laser based surveying instruments to compensate for off-vertical mounting configurations of the laser based surveying instruments.

30

It is another object of the present invention to provide a modular laser based distance measuring apparatus which includes a circuit for automatic compensation and correction for off vertical alignment of the instrument.

- 5 It is a still further object of the invention to provide an automatic tilt compensation circuit in a compass module of a modular laser based distance measuring instrument.

A typical laser based distance measuring instrument utilizes a fluxgate compass for bearing determinations. Alternatively, an angle  
10 encoder may be coupled with precise initial positioning of the base of the instrument for bearing determinations. In the case of an instrument using a fluxgate compass, the compass must be maintained at least within about 15 degrees of vertical at all times in order for the compass to provide accurate readings because of a floating ring core in  
15 the compass sensor.

In addition, distance measuring instruments typically include an single axis tilt sensor as an inclinometer for measuring the angle between the sighting line to the target and the horizontal plane through the instrument. When the instrument is rotated about the sight line  
20 such that the instrument is no longer vertically aligned, a geometric error is introduced to the vertical angle measurement because of this deviation.

The present invention is designed in its simplest form to alert the operator to unacceptable deviation angles from the vertical orientation  
25 of the instrument. In more complex forms, the present invention not only alerts the operator to unacceptable deviation angles from the vertical orientation of the instrument but also provides automatic correction of measurements made by the instrument for such deviations.

30 Basically, the method in accordance with the present invention of alerting an instrument operator to approaching unacceptable off vertical

alignment conditions when the instrument is mounted on a monopod or other one dimensional support comprises the steps of:

- a) providing a surveying instrument mounted on a one dimensional support;
- 5       b) providing a tilt sensor on the support capable of sensing a degree of tilt of the support from a vertical orientation of the support;
- c) sensing the degree of tilt; and
- d) communicating the degree of tilt to the operator.

The communicating step in the method above preferably also  
10 includes actuating an audible alarm when the degree of tilt exceeds a predetermined threshold value and may further include the step of varying the amplitude or frequency of the audible alarm as the degree of tilt passes beyond the threshold. Finally, the method may also include the step of automatically correcting measurements made by the  
15 surveying instrument.

A first embodiment of the apparatus in accordance with the present invention is a simple apparatus ensuring that distance and inclination measurements made with electronic surveying instruments, such as laser based instruments, are made without the conventional  
20 necessity for implementing very time consuming instrument support setup procedures. This first embodiment of the present invention is a self contained apparatus adapted to be fastened to any conventional instrument support such as a monopod or tripod. This apparatus is a battery powered two axis tilt measuring device fastened to the  
25 instrument support which provides an audible warning to the operator if the support is moved beyond a predetermined inclination angle in any direction from vertical.

The tilt compensation apparatus of this first embodiment in accordance with the invention basically preferably comprises a two axis  
30 tilt sensor, a power supply, and an alarm circuit. Alternatively, two single axis tilt sensors may be used to sense tilt along two orthogonal

axes. The alarm circuit may be analog or digital and drives the sensor or sensors, compares the sensor output to a predetermined tilt threshold, and provides preferably an audible alarm when the threshold is exceeded. An exemplary digital alarm circuit may include a  
5 microprocessor, an analog to digital converter, an oscillator/amplifier, and a speaker. These circuit components, the sensor and the power supply are all housed compactly in a box shaped housing which can be removably fastened to a support such as a monopod shaft.

The two axis tilt sensor has first and second opposing pairs of  
10 parallel peripherally spaced electrodes spaced symmetrically about a central output electrode. In the preferred arrangement of the first embodiment, a microprocessor drives the tilt sensor peripheral electrodes and receives, through an analog to digital converter connected to the pairs of spaced peripheral electrodes, the output of  
15 the tilt sensor.

The microprocessor coordinates not only the switching and driving of the electrodes, it also floats the idle pair of electrodes while the other pair is driven, instructs the analog to digital converter when to sample a first output from the output electrode when the drive signal is  
20 fed to the first pair of electrodes to determine one coordinate value of the tilt vector and instructs the analog to digital converter to sample a second output from the output electrode when the drive signal is fed to the second pair of peripheral electrodes to determine an orthogonal coordinate value of the tilt vector. The microprocessor then computes  
25 the sensed tilt magnitude. The microprocessor also provides an output to an audio oscillator/amplifier and speaker in this first embodiment to provide an audible indication to the operator of the relative angle of the instrument with respect to a vertical orientation. Preferably either or both of the pitch or amplitude of the audible indication may be varied  
30 with the intensity of the tilt magnitude away from a vertical orientation.

A second embodiment of the present invention incorporates the tilt sensor and audible alarm functions of the first embodiment into a compass module of a modular laser range finding instrument so that a separate housing is not required. In this preferred embodiment, duplication of components is minimized. The tilt sensor power supply is provided by the instrument power supply and the fluxgate compass module microprocessor is utilized to generate the tilt sensor drive signal and process the tilt sensor output signals in order to interpret the tilt angle and provide the alarm drive signal to the oscillator/amplifier and speaker. This embodiment is very efficiently arranged, eliminating the need for a separate tilt module housing.

A modular laser based distance measurement apparatus in accordance with this invention may also utilize the microprocessor to automatically compensate for non-vertical orientation of the monopod so that the operator preferably need only keep the monopod base securely on the reference point and the monopod shaft generally upright and within about 15 to 25 degrees of vertical alignment. This ensures accurate bearing measurements with the fluxgate compass and accurate distance and vertical angle measurements from the vertical reference point. The microprocessor in this case is configured and programmed to utilize the digitized tilt angle component values to automatically compensate measured bearing and range values during the off vertical condition of the instrument at the time of measurement as well as compensate single axis inclination measurements for errors introduced into the single axis tilt sensor when the ranging module of the instrument is not vertically aligned.

Another embodiment of the invention is utilized in an instrument configuration which has an angle encoder instead of a fluxgate compass. In this embodiment, the tilt compensation mathematics that must be used takes a different form than the corrections utilized in the compass module previously described.



Other objects, features and advantages of the present invention will become apparent from a reading of the following detailed description when taken in conjunction with the accompanying drawing wherein particular embodiments of the invention are disclosed as  
5 illustrative examples.

### BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a side perspective view of a modular laser based survey instrument mounted on a monopod with a tilt alarm module in  
10 accordance with a first embodiment of the invention fastened to the monopod.

Fig. 2 is a vector representation of a monopod supported instrument in an off vertical orientation taking a distance measurement to a target B.

15 Fig. 3 is a perspective view of a modularized laser based surveying instrument in accordance with a second embodiment of the invention.

Fig. 4 is a side view of a conventional electrolytic two axis tilt sensor utilized in the embodiments of the present invention.

20 Fig. 5 is a preferred drive circuit for operating the electrolytic two axis tilt sensor shown Fig. 4 in accordance with an aspect of the present invention.

Fig. 6 is a graphical representation of the drive voltage and output signals of the tilt sensor shown in Fig. 4 utilizing the circuit  
25 shown in Fig. 5.

Fig. 7 is a side perspective view of another modular laser based survey instrument on an alternative monopod support which utilizes a universal joint to maintain constant azimuth relationship to the measuring instrument while permitting inclination of the support off of  
30 vertical, particularly for use with an angle encoder module in accordance with a third embodiment of the invention.

Fig. 8 is a block diagram of the fluxgate compass and tilt compensation module of the instrument shown in Fig. 3.

## DETAILED DESCRIPTION OF THE INVENTION

### First Embodiment

Referring now to the drawing, Fig. 1 shows a first embodiment of a monopod supported modular range finding instrument 10 in accordance with the invention. The instrument 10 is fastened to a mounting platform 12 at the upper end of a monopod 14 which has a point 16 at its lower end. This point 16 is designed to be placed exactly on the reference point on the earth from which the measurement is to be taken with the monopod 14 held substantially vertically aligned above this point. The monopod 14 arrangement in Fig. 1 with a pointed tip 16 is particularly designed for use with a ring core fluxgate compass sensor.

The instrument 10 in this embodiment, as shown, may be any range finding instrument and is preferably a modular laser range finding system as is disclosed in copending United States Patent Application Serial No. 08/918,395, filed August 26, 1997 and entitled MODULARIZED LASER BASED SURVEY SYSTEM, the disclosure of which is hereby incorporated by reference in its entirety.

The instrument 10 includes a power supply 32, a compass module 24 and a laser range finder module 26 attached to the compass module 24. The compass module 24 preferably includes a ring core flux gate compass sensor located in a box 30 at the top of the module 24. A removable, stand alone tilt alarm module 34 is preferably removably fastened to the shaft of the monopod 14 via a conventional means such as hook and loop fastener strips, bolts, screws, clamps, etc. The module 34 has a housing 36 which includes a "V" or "U" shaped vertical groove 38 in the surface of the housing 36 for receipt and alignment with the monopod shaft 14 so that the housing 36 is

oriented in accurate parallel alignment with the axis of the monopod **14**. The housing **36** carries a two axis electrolytic tilt sensor **40** therein along an alarm circuit which may be analog or digital. The housing **36** preferably holds the a two axis tilt sensor **40** in alignment with the groove **38**, and further houses a microprocessor **42**, a power supply (batteries) **44**, a tilt sensor driver circuit **46**, an audio amplifier **48** and a speaker **50** as is shown in Fig. 5. The module **34** may include a display such as an LCD readout and one or more input buttons (not shown) for calibration and setup purposes.

Fig. 2 is a diagram of a monopod mounted instrument **10** on a monopod **14** as shown in Figs. 1 and 3 that is free to rotate about the point **16** such that the instrument **10** may be tilted from the vertical axis "A". This results in the instrument **10** being positionable anywhere on a hemispherical surface having a radius "h". When the instrument **10** is positioned off of the vertical axis and a measurement is taken, the instrument, and hence the compass sensor, is essentially tilted or rotated about its own axis toward the target. When the instrument **10** is positioned vertically, a distance measured from "O" will be accurately related directly to the ground point **16**. However, any distance measurement "D" to a distant object "B" which is made from a position "P" will be incorrect with reference to the ground point **16**, since the reference plane through "O" is no longer the horizontal base plane for the measurement. Further, the compass bearing will be incorrect. A plane through the point "P" and normal to the surface of a sphere having radius "h" (the length of the monopod **14**) is now the base plane for the measurement.

The true distance "d" between O and B and the correct compass bearing may be mathematically determined if the angle (direction) and magnitude of tilt to the point P is known. The two axis tilt sensor **40** senses this angle and magnitude. In most survey applications, the errors introduced is very low provided that the instrument **10** is

maintained within about 3 degrees of vertical. Consequently, in this first embodiment of the present invention, the tilt sensor **40** is used to merely warn the operator when the instrument is approaching or is beyond the acceptable limit for accuracy of the measurements being made.

Fig. **4** shows a two axis tilt sensor **40** separate from the tilt sensor module **34**. The sensor **40** may be one of any of a number of commercially available two axis tilt sensors and is preferably a two axis electrolytic tilt sensor such as an LCL series sensor which has nonmagnetic titanium leads. This LCL tilt sensor, series 0717-4400, is manufactured by The Fredricks Company, 2400 Philmont Avenue, Huntingdon Valley, PA 19006.

The sensor **40** preferably has titanium nonmagnetic leads so that it may be mounted right next to the actual compass sensor in the compass sensor module **30** on top of the compass module **24** in the monopod supported instrument **10** as is shown in Fig. **2** rather than in a separate, stand alone configuration as shown in Fig. **1**.

The electrolytic tilt sensor **40** basically is a closed glass, liquid containing envelope **52** with four parallel peripheral electrodes **54a**, **54b**, **54c**, and **54d** spaced 90° apart around a central electrode **56** extending into the interior volume of the envelope **52**. A conductive fluid **58** partially fills the sensor envelope **52**. The fluid surface **60** is essentially a plane that always remains normal to the direction of the gravitational force acting on the fluid **58** in the cell **40**. Consequently, when the monopod **14** is vertical and held stationary, the surface **60** of fluid in the sensor **40** will be stationary, level and horizontal and is at the same depth, i.e., point on each of the electrodes **54** in the cell **40**. Stated another way, the depth of fluid **58** around each electrode **54** is the same when the cell **40** is vertically oriented.

The electrolytic tilt sensor **40** operates by sensing changes in the conductance between each of the four peripheral electrodes **54** and the

central output electrode **56**. These sensors preferably have to be driven with AC signals and without any DC bias because a DC bias would degrade the fluid **58** by electrolysis.

Fig. **5** shows a simple drive circuit **46** in accordance with the invention for driving the sensor **40**. The circuit **46** comprises the microprocessor **42** which provides a drive signal to the tilt sensor **40** on lines **62x** and **62y**, a channel select signal to the tilt sensor **40** on line **64**, and an output signal on line **66** from the microprocessor **42** to the audio amplifier **48** and the speaker **50**. The power supply **44** consists of a pair of "AA" batteries, and provides power to the microprocessor **42**, the amplifier **48**, and the buffers of the drive circuit **46** which will be described shortly. The output of the tilt sensor **40** from terminal electrode **56** is connected through a buffer **68** to an analog to digital converter **70** and then to the microprocessor **42** for processing and eventual output to the speaker **50** via line **66** if the magnitude of the tilt angle exceeds a predetermined threshold value stored in the microprocessor **42**.

The electrode pins **54a** and **54b** constitute the "x" pair and electrode pins **54c** and **54d** constitute the "y" pair of electrodes for the two axis sensor **40**, since these pairs of opposing electrodes are orthogonal to each other. The electrode pins **54a**, **54b**, **54c**, and **54d** are each connected to the output terminal of one of four tristate buffer **72a**, **72b**, **72c**, or **72d** through an rf suppression coil **73**.

The microprocessor **42** provides two drive output signals, one on line **62x** and one on line **62y**, for the electrolytic sensor **40**. Each of these drive signals is exactly a 50% mark space ratio square wave. The drive output on line **62x** is connected to buffers **72a** and **72c** through an inverter **74x**. The drive output signal on line **62y** is connected to tristate buffers **72b** and **72d** through an inverter **74y**.

A channel select signal from the microprocessor **42** on line **64** is connected to the gates of each of the tristate buffers **72a,b,c,d**. The

channel select signal on line **64** is directly connected to the buffers **72a** and **72b** and connected through an inverter **76** to buffers **72c** and **72d**. This arrangement ensures that the idle pair of peripheral electrodes is floated. The channel select signal on line **64** effectively switches  
5 between the orthogonal pairs of electrodes and is synchronized to the channel being driven, either the x channel or the y channel, so that changes in the channel select between 0volts and 5 volts occur during a period when both electrodes in the operating pair are at 0 volts. This design provides a zero bias on the idle pair of electrodes in order to  
10 minimize electrolysis in the electrolyte and to minimize crossover interference between channels. Stated another way, the exactly synchronized channel select signal on line **64** is synchronized so that the drive signals are appropriately feed to the appropriate pairs of opposing electrodes such that the nondriven electrodes are floating  
15 while the driven electrode provides an output. This ensures that the x and y components of the tilt angle are accurately sensed without interference from the other component and minimizes the potential for degradation of the electrolyte in the cell.

The waveforms seen by the electrode pairs **54a,b** and **54c,d** are shown in the upper two portions of Fig. **6**. The channel select signal is shown in the third portion while the output voltage as seen on electrode **56** is shown in the lowest portion of Fig. **6**. Since the drive signal waveforms pass through inverters **74x,y**, the square wave sequences illustrated are inverted from those generated by the microprocessor **42**.  
20

25 There are several ways to operate the circuit shown in Fig. **6**. The following is merely one exemplary operational description in which each pair of electrodes is driven in alternating sequence. When an opposing pair of electrodes **54a** and **54b**, shown in Fig. **4**, which are diametrically opposite the central electrode **56**, is preferably driven with a waveform as shown in the upper portion of Fig. **6**, and the voltage on  
30 the central electrode **56** is monitored with the sensor **40** tilted off level,

the voltage on the central output electrode **56** may be as shown in the lowest portion of Fig. **6**.

Each drive pulse period, for ease of explanation, is broken into three preferably equal time segments as shown by the vertical dashed lines in Fig. **6**. The channel select line **64** may initially be held to zero volts as shown for driving the x channel electrodes **54a** and **54b** as illustrated. This enables the tristate buffers **72a** and **72b** and disables buffers **72c** and **72d**, thus providing a high impedance on electrodes **54c** and **54d**.

At the beginning of the first segment, a low drive pulse is produced on line **62x** by the microprocessor **42**. This low voltage is inverted by inverter **74x** to a positive going pulse which is fed through enabled tristate buffer **72a** to the electrode **54a** as shown in the top waveform of Fig. **6**. During this same time, the drive signal on line **62y** is maintained high and therefore the inverted output of inverter **74y** is low, e.g. zero volts. Therefore electrode **54b** sees zero volts. The other two electrodes **54c,d** are disabled and floated via the high impedance state provided by the tristate buffers **72c,d**. The resultant voltage output on electrode **56** is shown as reaching +4 volts in the lowest waveform of Fig. **6**.

During the second segment, when the drive pulse to electrode **54a** terminates, the drive signal out of the inverter **74y** goes high, to 5 volts, thus causing electrode **54b** to have a potential of 5 volts and electrode **54a** drops to zero volts. During this segment, the output voltage on electrode **56** drops to +1 volt. At the end of the second segment, the drive pulse on electrode **54b** drops to zero volts. During the third segment, when both of the drive signals are zero volts, the channel select signal may be synchronized to change to 5 volts, as shown, thus selecting tristate buffers **72c,d** and disabling and floating buffers **72a,b**.

The pulse sequence above described then repeats, except that now electrodes **54c** and **54d** are sequentially driven during the first and second segments. Specifically, at the beginning of the first segment, a low drive pulse is produced on line **62x** by the microprocessor **42**.

5 This low voltage is inverted by inverter **74x** to a positive going pulse which is fed through enabled tristate buffer **72c** to the electrode **54c** as shown in the top waveform of Fig. **6**. During this same time, the drive signal on line **62y** is maintained high and therefore the inverted output of inverter **74y** is low, e.g. zero volts. Therefore electrode **54d** sees  
10 zero volts. The other two electrodes **54a,b** are disabled and floated via the high impedance state provided by the tristate buffers **72a,b**. The output voltage on electrode **56** during this segment is +2 volts.

During the second segment, when the drive pulse to electrode **54c** terminates, the drive signal out of the inverter **74y** goes high, to 5  
15 volts, thus causing electrode **54d** to have a potential of 5 volts and electrode **54c** drops to zero volts. The output voltage on electrode **56** now changes to +3 volts. At the end of the second segment, the drive pulse on electrode **54d** drops to zero volts. During the third segment, when both of the drive signals are zero volts, the channel select signal  
20 may change again back to 0 volts, thus selecting tristate buffers **72a,b** and disabling and floating buffers **72c,d**.

Alternatively, the sequencing of the channel select signal on line **64** may be set to provide a series of consecutive x component sample values followed by a series of consecutive y component sample values  
25 rather than alternating between them. The series sequencing may be advantageous in providing an average set of x and y component values in field situations to improve resolution. For example, the channel select signal may be programmed to change every 10<sup>th</sup> cycle to provide a more stable tilt value based on time averages of the signals.

30 As shown in the bottom waveform of Fig. **6**, the output voltage on electrode **56** lags the rise and fall of the peripheral electrode voltages.



Therefore the ADC **70**, as indicated by the arrows, is programmed to sample the output waveform of electrode **56** after it has had an opportunity to stabilize during each of the segments.

The two detected or sampled values of voltage on the output electrode **56** sampled during the first and second segments for electrodes **54a,b** are algebraically subtracted in order to obtain the magnitude of tilt in the x direction. Similarly, the two detected or sampled values of voltage on the output electrode **56** during the first and second segments for electrodes **54c,d** are algebraically subtracted to provide the magnitude of tilt in the y direction. Thus the x value of tilt in the example illustrated in Fig. 6 is  $+4-(+1)=+3$  and the y value of tilt in the example illustrated is  $+2-(+3)=-1$ . The microprocessor **42** then preferably calculates the resultant vector magnitude and compares the result to a previously stored threshold value to determine whether an audible alarm is to be produced via amplifier **48** and speaker **50** via output line **66**. Alternatively, the microprocessor **42** may be programmed to directly compare the component values to previously stored component threshold values to determine whether an audible alarm is to be produced via output line **66** to amplifier **48** and speaker **50**.

If the tilt sensor is positioned level, the output on electrode **56** would be a constant +2.5 volts. As the sensor **40** is tilted from the level condition, the output voltage deviation with respect to the 2.5 volt level is symmetrical for each of the pair of excited electrodes. Thus measuring the voltage produced by exciting each electrode in the pair separately and then subtracting the two effectively doubles the sensitivity that a measurement made with only one electrode excitation provides.

One advantage of this essentially digital circuit described above over conventional two axis tilt sensor signal processing circuits is that the microprocessor **42** itself can provide a precise 50% square wave

drive signal so the x and y elements in the cell **40** to generate anti-phase signals on the central electrode **56**, thus minimizing the number of components required in the circuitry.

The drive circuitry above described is simple and efficient. To  
5 summarize, the magnitude of the voltage difference is proportional to the degree of tilt in the x or y components of the tilt vector. The sign of the difference is proportional to the direction of the x or y component of the tilt vector. The sensor is normally mounted so that when the instrument **10** is level there is a zero signal (in the exemplary  
10 embodiment this is 2.5 volts). Tilt one way you'll get a positive difference, tilt the other way you'll get a negative difference. The tilt warning device **34** of this first embodiment may thus be affixed to any survey instrument or mount for the instrument, provided the sensor **40** is oriented vertically with reference to the instrument itself. This is  
15 conveniently facilitated in the monopod arrangement illustrated in Fig. 1 by the groove **38** provided in the housing **36** in this embodiment.

Further, this first embodiment may be implemented in a simplified form utilizing analog circuitry rather than the digital circuitry as described in detail above. In an equivalent analog circuit, the  
20 microprocessor would be replaced by analog components and circuitry that generates the drive waveforms, performs the subtractions and comparisons described above to detect the degree of tilt and provides an alarm output tone that either changes pitch or intensity as the support and attached sensor deviates further from the level position.  
25 The threshold may preferably be preset in the simplified version. For example, the threshold may be set to begin issuing a tone at a deviation of 3 to 5 degrees from vertical. The threshold circuit could also include another step such as to change the alarm tone to an intermittent tone at the limits of a compass module such as about 15  
30 degrees. This would alert the operator when off vertical conditions are

tolerable and also when the monopod is tilted to an unacceptable tilt value.

### Second Embodiment

A second preferred embodiment of the invention is shown in Fig. 3. In this embodiment, the components of the tilt alarm apparatus are mounted within the compass module **24** and the tilt sensor **40** itself is housed within the compass sensor module **30**. In this second embodiment, the main instrument power supply **32** replaces the battery power supply **44**, an extra channel of the compass module microprocessor is used instead of the microprocessor **42**, and an ADC that is already in the compass module **24** which is used to digitize the electronic compass sensor output is used in place of the ADC **70** shown in Fig. 5 for the first embodiment. The output signal from buffer **68** is simply fed to an extra input channel on the analog to digital converter. Its output is in turn fed back to appropriate logic in the microprocessor in the compass module **24**. Lastly, the audio amp **48** and speaker **50** and the remainder of the circuit **46** remain as above described and simply mounted in the compass sensor module **30**. This second configuration maximizes utilization of available circuitry and components, while the first embodiment above described may be utilized with any conventional survey instrument.

A block diagram of the compass and tilt sensor circuitry for the second embodiment shown in Fig. 3 is shown in Fig. 8. Circuit **100** is a basic drive and sensing circuit for a fluxgate compass sensor **101** and the tilt sensor **40**. Circuit **100** also includes a microprocessor **112**, a tilt sensor drive circuit **134** as described above with reference to Fig. 5, a display controller **124**, a keypad **126**, an analog to digital converter **122** and a digital to analog converter **128**. The circuit **100** intermittently drives the fluxgate compass sensor core and senses and demodulates the composite compass sensor output signal in a demodulator **118**. The demodulator **118** and operational amplifiers **120**

together generates an x component and a y component of the sensed external magnetic field which can then be used to calculate the heading of the field or the direction of the field, relative field strength, and other such information.

5           Fluxgate compasses work exceedingly well when the location on the earth's surface is below the Arctic Circle or north of Tierra Del Fuego. Outside these latitudes, i.e., close to one of the poles, the horizontal component of the magnetic bearing signal is quite weak compared to the z component. Consequently, the achievable accuracy  
10           may be compromised. Thus the circuit **100** also includes an automatic dual range sensitivity circuit **110** which is controlled by the central microprocessor **112** which automatically increases coupled component sensitivity in order to compensate for decreased magnetic field strength when the compass is being utilized in latitudes near either of the  
15           earth's magnetic poles.

          The fluxgate compass sensor **101** is driven by a flux gate drive circuit **114** which provides a precise 50% duty cycle square wave at an operating frequency optimized for the particular fluxgate sensor **101**. In the preferred embodiments shown, this frequency is preferably a  
20           precise 22.5 kHz signal generated in the fluxgate drive circuit **114** which has, as one input, a voltage controlled oscillator **116**, which is in turn controlled by the microprocessor **112**. The fluxgate drive circuit **114** also provides an exact double frequency, 45kHz square wave signal to a demodulator circuit **118**. The output of the compass x and y  
25           coils is fed also to the demodulator circuit **118** which demodulates, i.e., removes the coupled drive coil signal component from the output signal for each of the x and y components. The demodulated x and y component signals are then differentially amplified in operational amplifiers **120** and then sent to an analog to digital converter (ADC)  
30           **122**. The ADC **122** then sends the digitized x and y components of the bearing signal to the microprocessor **112** for calculation of the bearing

or direction. The resultant bearing is then displayed via display controller **124**.

An input keypad **126** on the face of the compass module **24** is used to provide manual input to the microprocessor **112** such as  
5 operational mode selections and calibration mode values and other information required for calibration of the instrument.

DAC **128** provides a dithering signal **130** to the operational amplifiers **120** to provide increased accuracy between the digital steps typically generated by the ADC **122**. This dithering signal is also  
10 provided to the operational amplifier **136** which is equivalent to the buffer **68** in the first embodiment. The operational amplifier **136** output is fed to ADC **122** which in turn converts the analog tilt sensor **132** output into digital values of the x and y components of tilt which is then sent to the microprocessor **112**. As with the compass signals, the  
15 dithering signal **130** provides small changes to the baseline output voltage signals which, over time, provides increased accuracy between the digitized output steps otherwise provided by the DAC **128**.

The two axis tilt sensor **40** is driven by a tilt sensor drive circuit **134** controlled and timed by the microprocessor **112** as above  
20 described with reference to the first embodiment. Thus the waveforms and output operational descriptions provided with reference to Fig. **6** apply equally well to this second embodiment. The sensor **40** through the microprocessor **112** preferably also provides a warble tone via a speaker **50** (not shown in Fig. **8**) mounted in the compass module **24**  
25 which is audible to the user and which indicates a progressive warning to the user as the platform of the instrument shifts off of a horizontal plane beyond a preset amount.

### Third Embodiment

Fig. **7** shows a third embodiment of the instrument **10** on an  
30 alternative monopod **14** support which has a plate **18** at the bottom in place of the point **16**. This plate **18** has teeth **20** on the bottom to

20

engage the ground and keep the plate **18** from sliding or rotating from the reference placement. The plate **18** is fastened to the lower end of the monopod **14** shaft via a universal joint **22**. The universal joint **22** permits the shaft of the monopod **14** to be inclined from vertical but  
5 prevents rotation or twisting of the platform **12** about the monopod axis. In other words, the joint **22** prevents changing the azimuthal orientation of the mounting platform **12**.

The alternative arrangement of the monopod **14** shown in Fig. 7 with a base plate **18** and universal joint **22** must be used when a angle  
10 encoder module **28** is interposed between the mounting platform **12** and the compass module **24**. This is necessary since, when an angle encoder **28** is used, there must be a stable reference angular position for the angle encoder to sense deviation from, i.e. the monopod **14** cannot twist, hence the plate **18** and universal joint **22** are necessary.

15 The instrument **10** in this third embodiment is the same as in the second embodiment and includes the circuit **100** as above described with reference to the second embodiment. The instrument **10** includes a laser range finder module **26** and compass module **24** mounted on top of an angle encoder **28** which is in turn mounted on the platform **12**.  
20 The compass module **24** also includes a fluxgate compass sensor module **30** mounted on top so as to be displaced from the instrument power supply module **32**. The compass module **24** houses a microprocessor **112** to which the ring core compass sensor **101** located in the compass sensor module **30** and/or angle encoder **28** is  
25 connected, and supports an input keypad and an LCD readout as shown.

As just mentioned, the compass sensor module **30** may or may not house a fluxgate compass sensor **101**. In either case, the module **30** includes a tilt sensor **40** as in the second embodiment. The angle  
30 encoder **28** in this embodiment is connected directly to the microprocessor **112**. The tilt sensor **40**, tilt sensor drive **134**, tilt output

operational amplifier **136**, DAC **128** and ADC **122** remain connected as shown in Fig. **8** and operate as described above.

Referring now to back to Fig. **2**, it may be recalled that this figure illustrates the errors that may be introduced by having a tilted support for the measuring instrument **10**. Assume the vertical height **h** of the laser range finder **26** is known and the point **16** of the monopod support **14** is placed at the reference or control point on the ground. If the instrument **10** were perfectly vertically aligned along axis **A**, then no errors are introduced. However, if the monopod **14** is inclined to the position as indicated by the arrow "**h**", then the actual vertical height above ground is actually less than the height **h** and the laser range finder **26** is somewhere on the circle "**e**" which is laterally displaced from the axis **A**. The position of point "**P**" relative to axis **A** is represented by the tilt sensor vector. The two axis tilt sensor **40** determines the x and y coordinates of this tilt vector and mathematically the microprocessor **112** can accurately determine the magnitude of offset distance "**l**" and the angular location of the range finder **26** on the circle **e** relative to the compass zero or true North. This information may then be used by the microprocessor **112** to compensate for magnitude and direction of the offset to correct for off vertical mounting of the laser range finder **26**.

The microprocessor **112** in both the second and third embodiments shown in Figs. **3** and **7** may be programmed to automatically correct for the effects of measurements made with these tilted monopod configurations. Thus the microprocessor **112** can tilt correct azimuth errors when the instrument is off horizontal. In addition, a primary function of the invention in these embodiments is to automatically correct the vertical angle measurement made by the internal tilt sensor in the laser distance module **26**. In this situation, the audible alarm feature described above may be eliminated or

alternatively provided only when the instrument is tilted beyond the functional capabilities of the fluxgate compass (if used).

Since the x and y coordinates of the tilt vector are known from the tilt sensor **40** via the operational amplifier **136** and ADC **122**, and  
5 the length of the monopod **14** is known, the microprocessor **112** can simply utilize matrix transformation algorithms to transform measured distance and bearing to target to actual bearing, elevation and range to target information to the horizontal planar coordinate system. Such an automatic compensation scheme thus frees the operator from the  
10 necessity of having to laboriously mount the base of the survey instrument on a horizontal plane and maintain alignment plumb with the control point on the earth in order to achieve extremely high accuracy results.

For example, the second embodiment shown in Fig. **3** may  
15 include a software routine in the microprocessor **112** which makes the appropriate corrections. Referring now to Fig. **2**, the instrument **10** may be positioned with the point **16** as shown and the rangefinder **26** positioned at point "P". In this position, the rangefinder **26** is no longer upright. The rangefinder **26** is equivalently being rotated about its  
20 sighting axis to the target "B". Thus if the normal x, y, z coordinate system is used for a monopod **14** with a height "h", the following relationships apply. If the monopod is held vertically above the ground reference point shown in Fig. **2** as axis "A", the coordinates of the instrument **26** with respect to the ground are x=0, y=0, and z=h.  
25 However, when the monopod is tilted at an angle  $\phi$  to the z axis and at an angle  $\theta$  to the x axis, then the coordinates of the instrument with respect to the ground reference point are given by the following relationships.

30

$$x = h \cdot \sin(\phi) \cdot \cos(\theta)$$

$$y = h \cdot \sin(\phi) \cdot \sin(\theta)$$



23

$$z = h * \cos(\phi)$$

The real target bearing angle, the true distance to target from the control point and the actual or real elevation to target are determined via software through this and similar geometric relations determined from the measured values of bearing, tilt angle, distance, and target elevation since the length **h** of the instrument **10** from the control point at the tip **16** is known.

The laser rangefinder also contains an internal tilt sensor for measuring the vertical inclination angle to the target. The measured vertical inclination angle will depend on the orientation of the instrument. For example, if the instrument is turned or rotated about its own axis as indicated in the Fig.2, i.e., rotated about the sighting axis, by an angle  $\rho$  from an upright orientation, the measured angle of inclination to the target "**B**" is  $\phi$ , then the true or actual vertical inclination angle  $\theta$  is given by the following relationship.

$$\theta = \tan^{-1}(\tan(\phi) * \cos(\rho))$$

The above relationship is exact if the inclination tilt sensor acts as a pendulum within the rangefinder housing. For other internal tilt sensor geometries, additional corrections may be applied.

The correction angles and equations are different for the third embodiment shown in Fig. 7. This is because the instrument **10** utilizes an angle encoder in which the sensed angle is not dictated by the magnetic field effects on a horizontally oriented floating ring core sensor but is purely geometrically determined by the encoder rotational movement with respect to a zero orientation. If the plane of rotation of the angle encoder **28** is not in the horizontal reference plane then the measured horizontal angle to the target will differ from the actual horizontal angle target. For example, if the apparatus **10** shown in Fig.

7 was positioned as in Fig. 2, that is, with the rangefinder at point **P** and aimed at the target **B**, then the plane of the angle encoder will be tilted from the horizontal. As far as the angle encoder is concerned, this is equivalent to the plane of rotation of the encoder being tilted or  
5 rotated about the y axis by an angle  $\phi$ . A typical conventional coordinate scheme is the y axis is directly ahead, the positive x axis extends to the right of the origin, and the z axis is vertically up. The measured "horizontal" angle i.e., angle with respect to the x axis, to a target **B** in the tilted plane is  $\theta$ , then the true or actual horizontal angle  
10  $\omega$  to the target **B** in the real horizontal reference plane is given by the following relationship.

$$\omega = \text{Tan}^{-1}(\text{Tan}(\theta)/\text{Cos}(\phi))$$

15 The correction of the laser tilt sensor reading as discussed above would also apply to the laser rangefinder **26** in the monopod configuration of Fig. 7.

The above corrections and matrices coordinate transformations to determine accurate measurements from the control point may be  
20 integrated into the microprocessor **112** so that the values of bearing and range read by the user are automatically corrected to the control point in all of the configurations shown and described. In addition, other corrections may be programmed into the microprocessor **112** such as corrections for inherent nonlinear characteristics of the tilt  
25 sensor **40**, the internal inclination tilt sensor in the rangefinder **26**, and the fluxgate compass sensor **101**. These characteristic correction factors depend on the particular sensors utilized and therefore must be programmed into the microprocessor **112** on a case by case basis depending on the particular sensors being used.

30 While there have been described above the principles of the present invention in conjunction with specific embodiments, it is to be

clearly understood that the foregoing description is made only by way of example and not as a limitation to the scope of the invention. As a case in point, the embodiments illustrated and described above all involve the use of a two axis tilt sensor **40** or **132**. These sensing functions performed by the sensor may also be performed by two single axis tilt sensors or even one single axis tilt sensor that is mounted on the one dimensional support. In the latter case, the single sensor would be swivel mounted or ball bearing ring mounted to the support in such a way that it always rotates to and essentially hangs in the direction of tilt. Where two single axis tilt sensors are used, they would have to have their reference axes oriented parallel and oriented at right angles in the horizontal plane. Their outputs may be integrated into the drive circuit shown in Fig. 8. Particularly, it is recognized that the teachings of the foregoing disclosure will suggest other modifications to those persons skilled in the relevant art. Such modifications may involve other features which are already known per se and which may be used instead of or in addition to features already described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure herein also includes any novel feature or any novel combination of features disclosed either explicitly or implicitly or any generalization or modification thereof which would be apparent to persons skilled in the relevant art, whether or not such relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as confronted by the present invention. The applicants hereby reserve the right to formulate new claims to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

## CLAIMS

What is claimed is:

1. A tilt sensor drive circuit for use with a tilt sensor arrangement having two pairs of opposing peripheral electrodes each pair spaced equally apart about a central signal output electrode to provide an output representative of tilt of said sensor arrangement from a horizontal orientation, said circuit comprising:
  - four tri-state buffers each having an output connected to one of said peripheral electrodes;
  - 10 a drive signal generator producing a first and a second drive signal, said first drive signal being connected to an input terminal of one of said tristate buffers in each pair of opposing peripheral electrodes, said second drive signal being connected to an input terminal of another of said tristate buffers for the other electrode of
  - 15 each pair of said opposing peripheral electrodes; and
  - a channel select signal generator producing a channel select signal connected to the gates of each of said tri-state buffers for one pair of opposing peripheral electrodes and connected through an inverter to the gates of each of said tri-state buffers for the other pair of
  - 20 said opposing electrodes.
2. The circuit according to claim 1 wherein said channel select and said drive signals are generated by a microprocessor.
3. The circuit according to claim 1 wherein each of said first and second drive signals is substantially a 50% mark space ratio square
- 25 wave.
4. The circuit according to claim 3 wherein a change of said channel select signal is synchronized with said drive signals.
5. The circuit according to claim 4 wherein said channel select signal and said drive signals are derived from a microprocessor.
- 30 6. A tilt alarm apparatus for indicating when a member exceeds a

predetermined tilt variance from a vertical orientation comprising:

a housing fastened to said member;

a power supply in said housing;

5 a two axis electrolytic tilt sensor mounted in said housing having  
a central output electrode and two pairs of opposing peripheral  
electrodes equally spaced about said central electrode; and

a signal generator in said housing connected to said power  
supply and to said sensor, said generator producing drive signals and  
an alarm signal upon receipt of a tilt signal above a threshold;

10 a sensor drive circuit connected to said signal generator, said  
circuit selectively driving each of said pairs of peripheral electrodes to  
produce said tilt signal; and

an alarm circuit connected to said generator producing an  
audible alarm upon receipt of said alarm signal.

15 7. The apparatus according to claim 6 wherein said signal  
generator produces a first and a second drive signal and a channel  
select signal.

8. The apparatus according to claim 6 wherein said alarm circuit  
produces an alarm sound through a speaker which varies in amplitude  
20 in proportion to the degree of tilt above a predetermined value.

9. The apparatus according to claim 6 wherein said alarm circuit  
produces an alarm sound through a speaker which varies in frequency  
in proportion to the degree of tilt signal from said tilt sensor above a  
predetermined value.

25 10. The apparatus according to claim 6 wherein said housing has an  
external linear channel in an outer surface of said housing for receiving  
and aligning said tilt sensor module with a portion of said member.

11. The apparatus according to claim 10 wherein said member is a  
support monopod having an elongated shaft.

30 12. The alarm according to claim 11 wherein a portion of said  
elongated shaft is received in said channel to align said tilt sensor with

said monopod shaft.

13. A tilt alarm module adapted to be fastened to a monopod support for a distance measuring instrument in which the alarm module senses and indicates when the monopod support exceeds a predetermined inclination angle from a vertical orientation, said module comprising:

a housing fastened to said monopod support;

a power supply in said housing;

- a two axis electrolytic tilt sensor mounted in said housing having a central signal electrode aligned parallel to said monopod support and two pairs of opposing peripheral electrodes equally spaced about said central electrode;

- a microprocessor in said housing connected to said power supply, said microprocessor producing a first and a second drive signal connected to said peripheral electrodes and producing a channel select signal for selecting between said opposing pairs of electrodes, said microprocessor further including a tilt input connected to said central signal output electrode and an alarm output providing an alarm signal when said tilt input from said tilt sensor exceeds a predetermined value.

14. The alarm according to claim 13 further comprising a sensor drive circuit receiving said drive signals and said channel select signal, said circuit selectively connecting said first and second drive signals to each of said pairs of peripheral electrodes while floating an idle pair of electrodes.

15. The alarm module according to claim 13 further comprising an analog to digital converter connected between said output electrode and said tilt input on said microprocessor for sampling said sensor output.

16. A laser based surveying instrument comprising:  
a distance measuring module; a compass module; and a power supply module mounted on a monopod support, wherein said compass

module includes a two axis electrolytic tilt sensor fastened to said compass module, said tilt sensor having a central signal electrode oriented parallel to an axis of said monopod support and two pairs of opposing peripheral electrodes equally spaced about said central  
5 electrode, said compass module including a drive circuit for said tilt sensor and an alarm circuit for providing an alarm when said monopod support is tilted beyond a predetermined threshold tilt value from vertical.

17. The instrument according to claim 16 wherein said compass  
10 module includes a microprocessor producing a first and second drive signal connected to opposing electrodes in each pair of said peripheral electrodes of said tilt sensor.

18. The instrument according to claim 17 wherein said  
15 microprocessor further generates a channel select signal operably connecting said drive signals to said pairs of opposing electrodes.

19. The instrument according to claim 18 wherein said microprocessor further provides an alarm signal to an audible alarm circuit when said tilt exceeds said predetermined threshold value.

20. The instrument according to claim 16 wherein said drive  
20 circuit includes four tri-state buffers each connected to one of said peripheral electrodes, said drive signal output being directly connected to an input terminal of said tri-state buffer for one electrode in each pair of peripheral electrodes and said drive signal being connected through a first inverter to an input terminal of said tri-state buffer for the other  
25 electrode of each pair of said opposing peripheral electrodes.

21. The instrument according to claim 20 wherein said channel select signal from said microprocessor is directly connected to a gate of each of said tri-state buffers for each one of a first of said pairs of electrodes and is connected through a second inverter to each of said

tri-state buffers for each one of said pairs of electrodes.

22. The instrument according to claim 16 wherein said alarm is audible when said inclination exceeds about 5 degrees inclination from vertical

5 23. A method for alerting a surveying instrument operator to approaching unacceptable off vertical alignment conditions of the instrument when the instrument is mounted on a one dimensional support comprising the steps of:

- 10 a) providing a surveying instrument mounted on a one dimensional support;
- b) providing a tilt sensor on the support capable of sensing a degree of tilt of the support from a vertical orientation;
- c) sensing the degree of tilt; and
- d) communicating the degree of tilt to the operator.

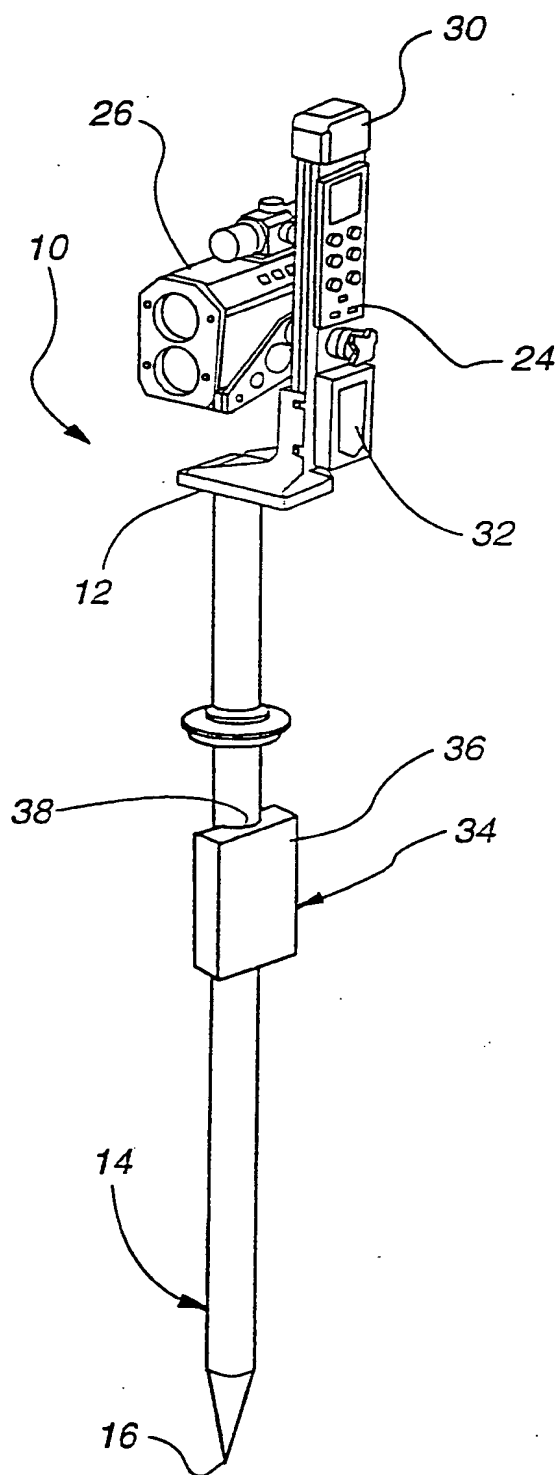
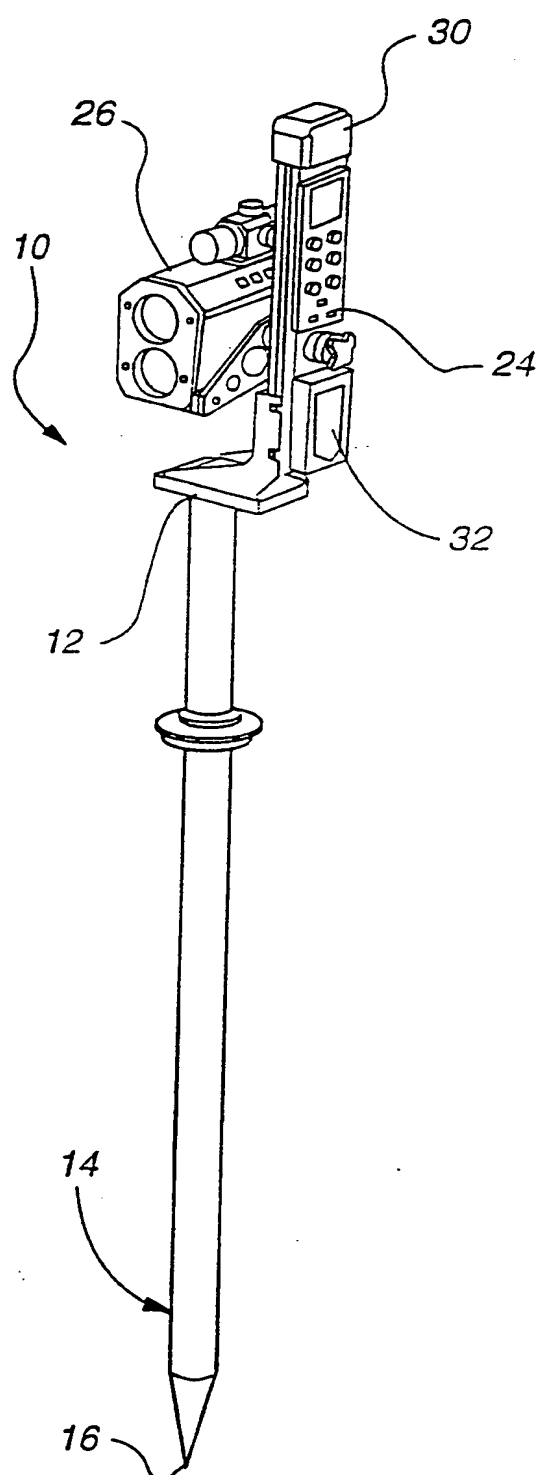
15 24. The method according to claim 23 wherein said communicating step includes actuating an audible alarm when the degree of tilt exceeds a predetermined threshold value.

25 25. The method according to claim 24 wherein said communicating step include the step of varying the amplitude or frequency of the audible alarm as the degree of tilt passes beyond the threshold.

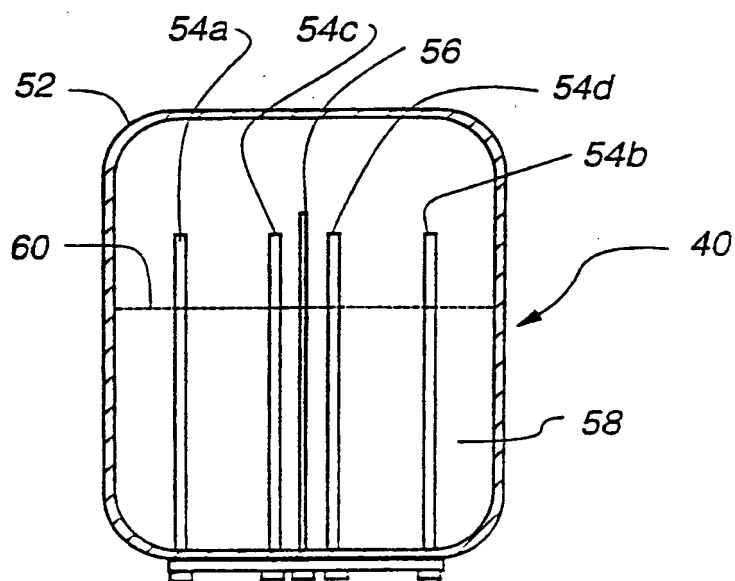
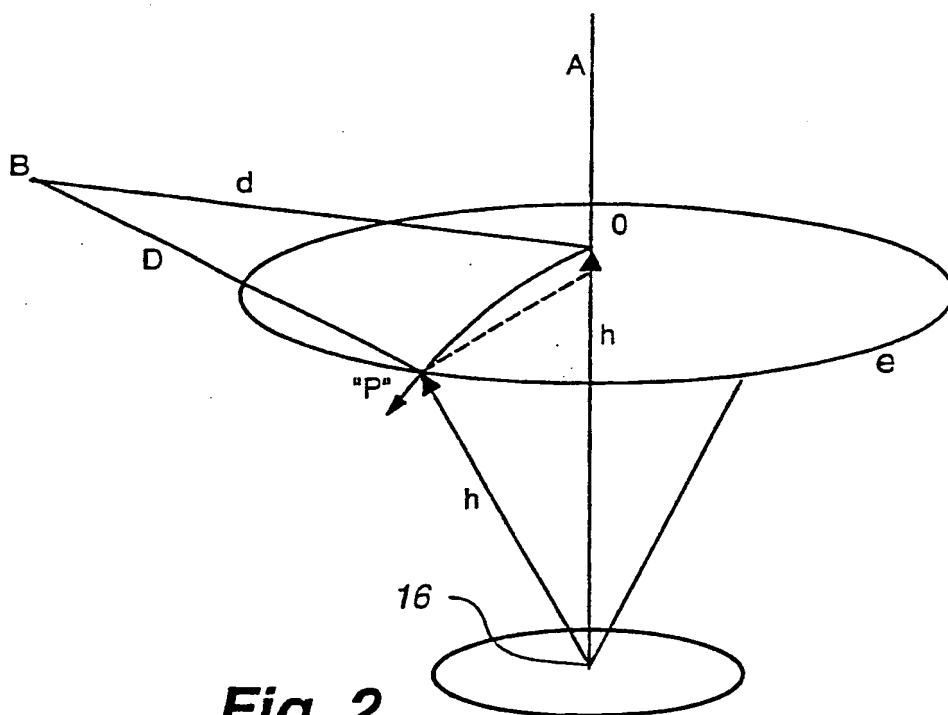
26. The method according to claim 23 further comprising the steps of determining a correction for measurements made in said off vertical alignment and automatically correcting said measurements for inaccuracies introduced by said off vertical alignment.



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**Fig. 1****Fig. 3**

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**Fig. 4****Fig. 2**

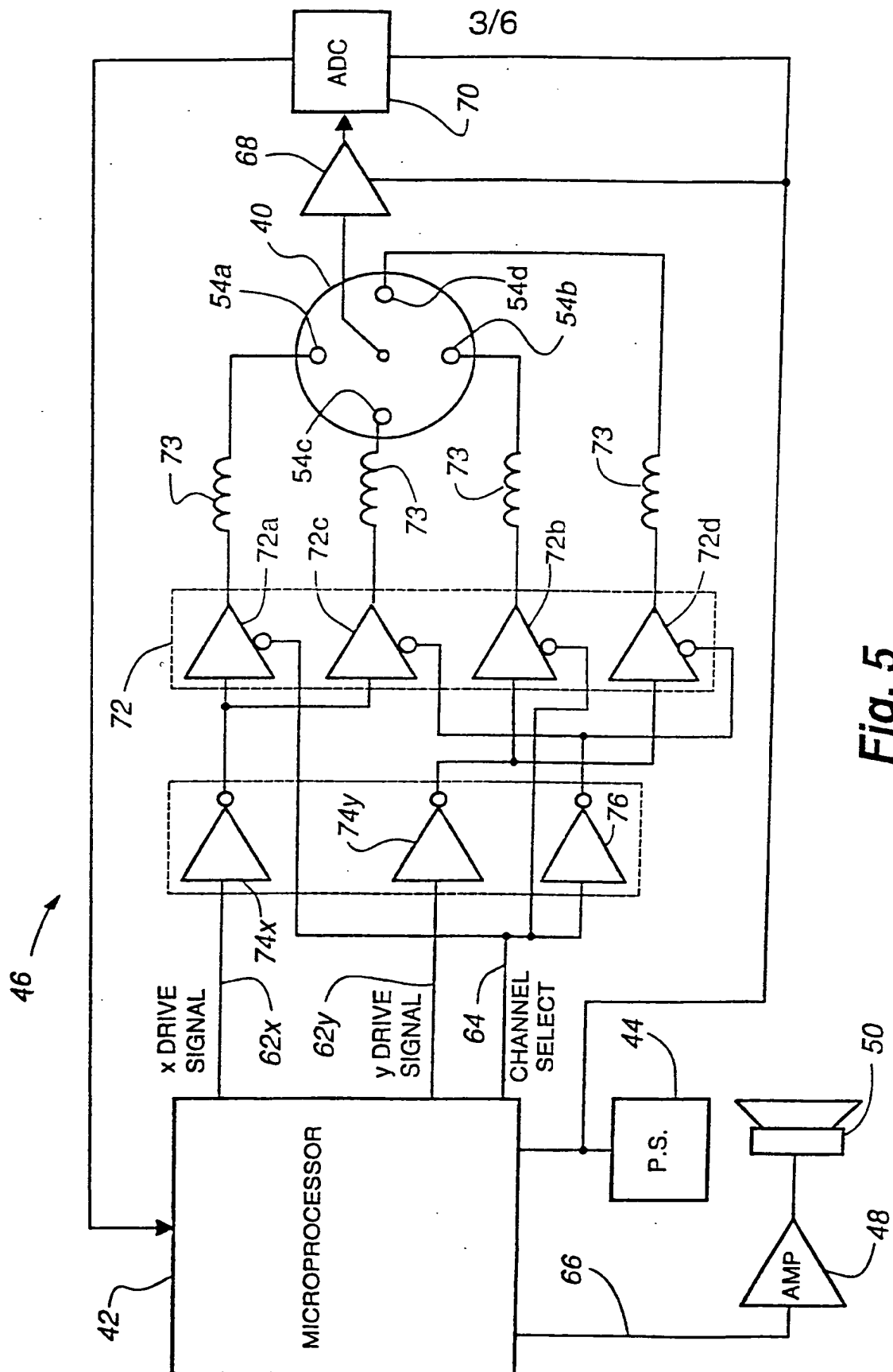
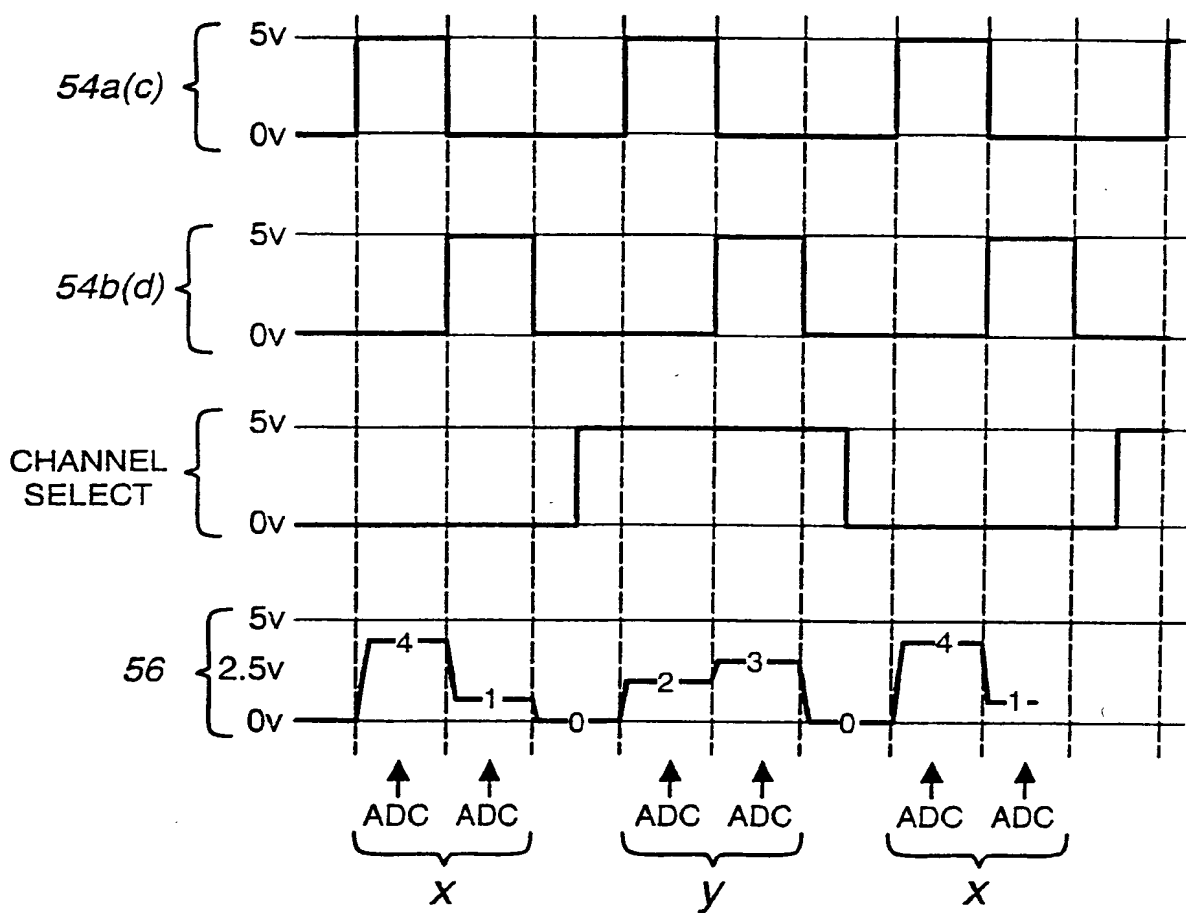
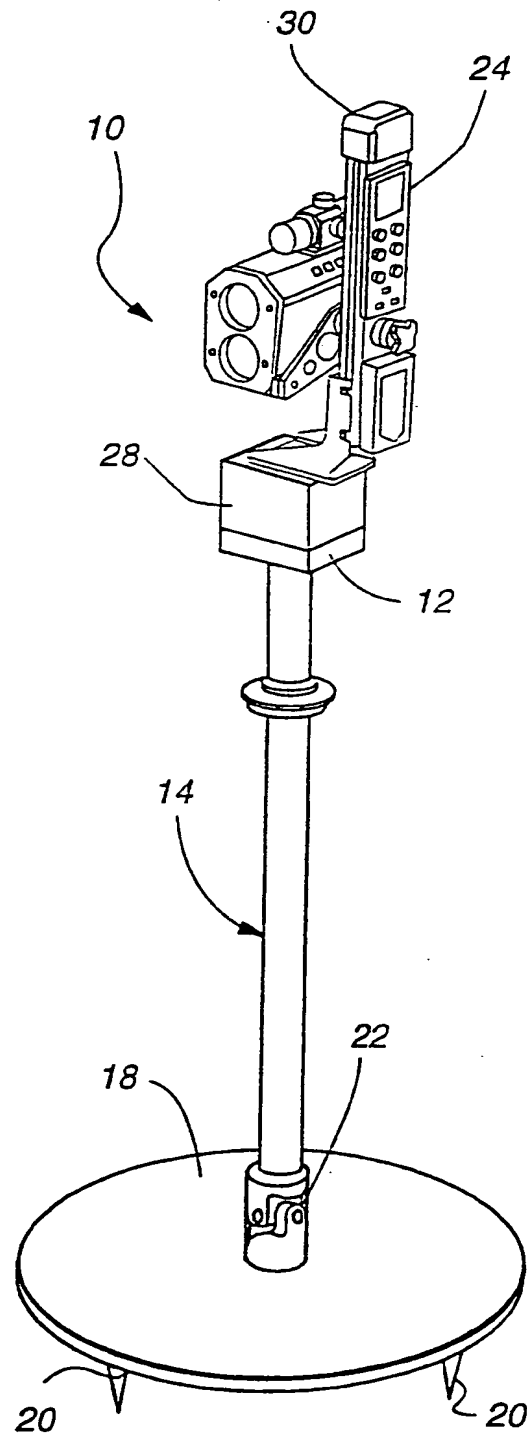


Fig. 5

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**Fig. 6**

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**Fig. 7**

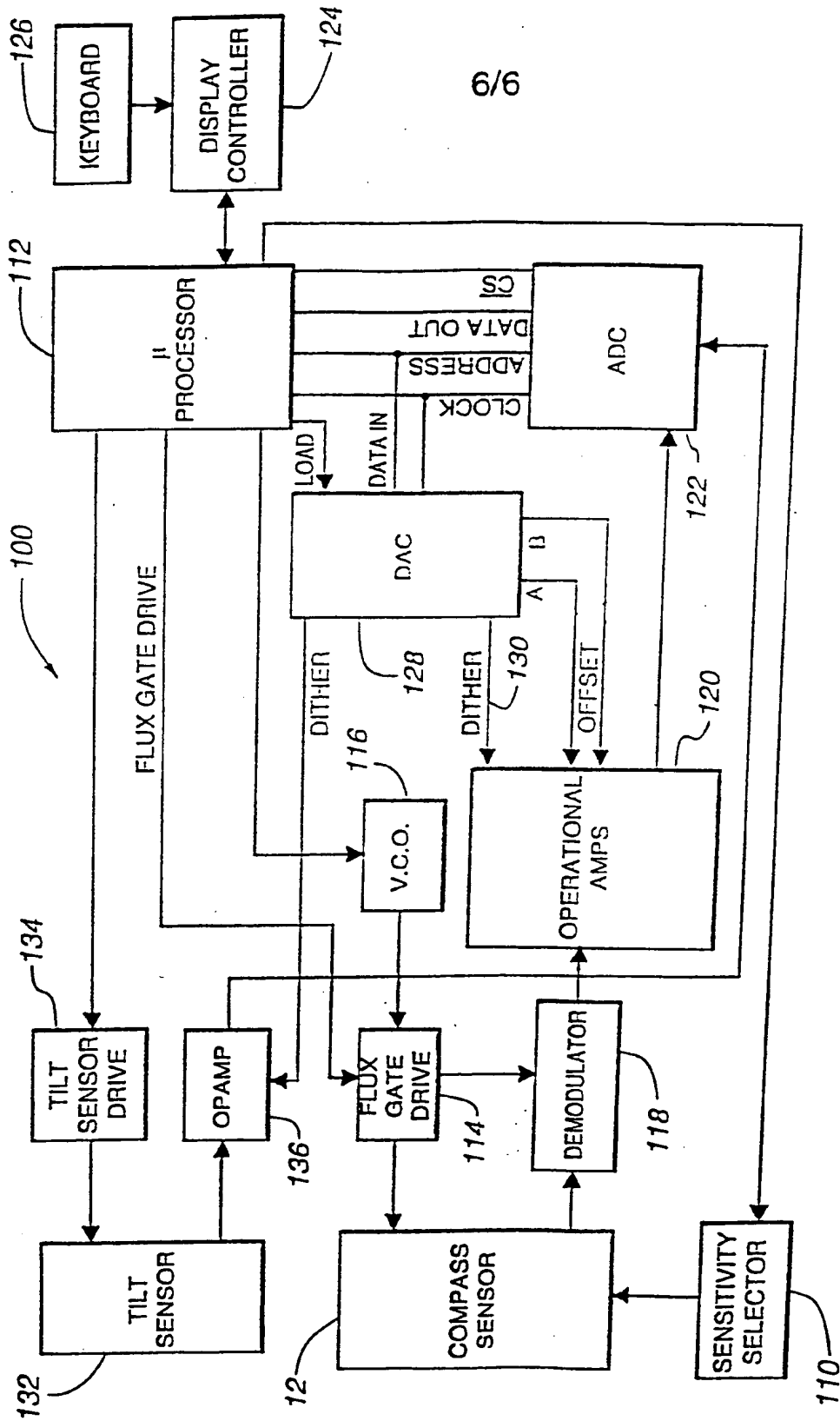


Fig. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/09207

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :G08B 21/00

US CL :340/689

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 340/689; 33/366, 365, 1 CC

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,612,679 A (BURGESS) 18 March 1997, the whole document.	1-26
A	US 5,313,713 A (HEGER et al) 24 May 1994, see Figure 2.	1-12
A	US 5,159,401 A (DECKER, Jr.) 27 October 1992, Figures 1-5.	13-15
A,P	US 5,859,693 A (DUNNE et al) 12 January 1999, the whole document.	16
A	US 4,949,089 A (RUSZKOWSKI, Jr.) 14 August 1990, the whole document.	13-22

☐ Further documents are listed in the continuation of Box C.
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Date of the actual completion of the international search

16 JULY 1999

Date of mailing of the international search report

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